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A Framework for the Improvement of Frugal Design Practices

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Abstract: Current frugal design practice is focused on the cost reduction of the product. Despite advancements in the domain of frugal Innovation, it is not systematized to develop products for all sets of users, including marginalized society. Many design researchers and engineers now dedicate time and knowledge to producing practical solutions to enhance the quality of life of the marginal community. The approach currently being adopted restricts the development of products intended for all segments of the users. In this paper, cumulative frequency distribution analysis and the Relative Importance Index is used to identify the essential attributes, which contribute to delivering actual frugal products in terms of functionality, usability, performance, affordability, accessibility, aesthetics, and robustness. The framework is beneficial to eradicate the discriminatory effect of being labeled as "Jugaad" users.

Keywords: frugal design; usability; functionality; reverse innovation

1. Introduction

Frugal design (FD) is one of the critical areas to fulfill the needs of the people in a resource-limited society. Frugal innovation (FI) has been identified as an essential element in improving the quality of life economically as well as socially. The current product development process in FD is primarily focused on (i) elimination of components, (ii) compromise with the quality (iii) reducing functionality, usability and aesthetic appeal, to reduce cost. There are a number of FI definitions available in the literature, and the most commonly cited one is the following: "Frugal innovation is a process of reducing the complexity and cost of a good and its production." Usually, this refers to removing nonessential features from a durable good to sell it in developing countries or low to mid-income market segments. The objective of FI is to reduce the complexity, overall cost, and enhance the functionality of the product, service, and systems while delivering high user value and affordable solutions within the economic range [1]. The process associated with mainstream or specialized products is directed towards specific audiences. FD processes focus on a unique set of users, i.e., people who are at the bottom of the pyramid, along with developing and undeveloped nations such as India, Nepal, Africa, etc. The outcome of the FD methodology would not be useful even if the product was aesthetically not attractive to all users, including mainstream users.

In this work, seven key elements (functionality, usability, performance, affordability, accessibility, aesthetics and robustness) for frugal innovation design are identified with the help of an cumulative frequency distribution analysis. A further descriptive-statistical tool called the Relative Importance Index (RII) is used, which helps to gain relative importance for each of these vital attributes identified

individually. RII is evaluated by obtaining the responses from two sets of respondents, design experts, and design practitioners, on a five-point Likert scale. Finally, the mean RII of every attribute is investigated based on the categorization of attributes, i.e., most essential, essential, desirable, and neutral contributing towards designing a frugal innovation. The main objective of this study is to draw an inference that the current FD practice is sufficient to develop frugal products as per the definition of FI and to introduce essential attributes to improve the FD practice to cater to all segment of users. A case study was conducted with the help of the Pugh chart method to gauge the frugality based on the identified attributes.

2. Background Study

Innovation is a popular subject of research in organizational philosophy [2]. It is identified as one of the prime indicators in obtaining a competitive advantage [3,4]. The nature and importance of innovation has been highlighted and discussed by [5–7]. In contrast to the developed economies, the developing economies implement a bottom-up strategy to the technology development by the reverse engineering of the commercial products. This gives rise to an unconventional method of product development where the information flows in a reverse direction (from distribution to the manufacturing to the research) [8]. This reverse trend is referred to as 'Frugal Innovation'. Such innovations are typically aimed at obtaining a low cost alternative to the existing technology and thus lack in meeting the intended functionality of the product [9,10]. There exists various versions of FD in the literature, namely, frugal engineering, reverse innovation, jugaad, constraint-based innovation [3,11,12]. However, a standardized conceptual approach is still missing in the literature. Immelt et al. [13] distinguished FI from the reverse innovation as the FIs are intended towards niche consumers and are not aimed for mass production. On the contrary, reverse innovation aims at developing profit-oriented businesses aiming at the worldwide distribution. This argument is further supported by Singhal [14], in that the frugal innovations are the innovations which are only restricted to their originating countries and are not intended for a global business.

Brem and Ivens [15] advocated the philosophy of the frugal innovation by stating that such designs involve simplicity at the same time imbibing functionality of the product. The authors further claim that FIs are sustainable in nature and utilizes less material and resources. The market performance of such innovations is directly linked with the degree of improvements achieved by the manufacturer. Weyruch and Herstatt [16] discussed three main characteristics of a frugal innovation: (a) significant decrease in the costs, (b) focus on product functionality, and (c) optimal performance. Figure 1 shows two examples of frugal innovation: Mitticool and VScan. Mitticool is an inexpensive refrigerator for Indian villages and towns with energy shortages. The cost of the refrigerator is 60% less compared to a commercial refrigerator. It can primarily be used for cooling water, dairy products, vegetables and fruits, thereby performing its intended function. However, the refrigerator lacks the freezer compartment and lightning. As it satisfies all the three criteria mentioned above, it can be considered as frugal innovation. Similarly, Vscan is a handheld scanner developed for the Chinese markets. The cost of this ultrasound scanner is 85% lesser than the existing commercial product. The core-functionalities of an ultrasound scanner are matched and the performance level also fits to the intended purpose. Thus, this can also be classified as an example of a FI.

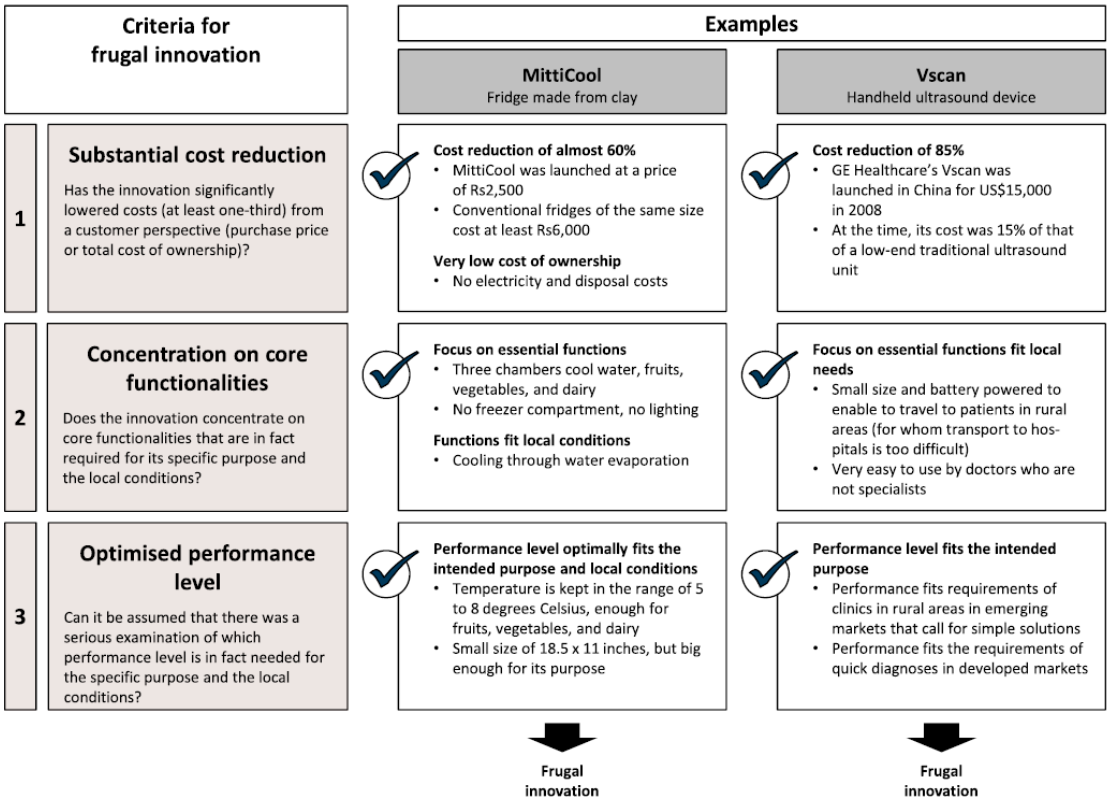

Figure 1. Examples of frugal innovation. Image adapted from [16].

Though FIs are mainly targeted at low-income consumers in developing countries, a few of these pass through to developed countries [17]. Some researchers claimed that FIs seek to challenge current product design frameworks with substantial cost savings on the one hand, while retaining customer satisfaction on the other [18]. The features of FIs are distinct from those of mainstream products, and they need to be viewed from a novel viewpoint [19]. Therefore, FIs require specific explanations for a variety of main reasons, such as:

1. Distinctive geographical background of the FIs [20]. Globalization is increasing the status of the middle class in developing economies, whose demand for better living conditions places our resources under pressure.
2. Unique distribution method [21]. For example, FIs can be distributed and sold by the local community using the FIs, who are also trained as salespersons. This can help in bringing down the distribution costs.
3. They ought to have a new business model [9]. Traditionally, business models of firms in the emerging countries do not focus on the resource-constrained customers, but rather are concentrated on the privileged few who have the higher purchasing power. Western businesses wishing to participate in frugal innovation need to create operational frameworks and skills to produce frugal goods.
4. Unique distribution channel is needed [22].
5. Crude design of the FIs compared to the mainstream products, as the FIs are more focused on the low cost of the intended product.
6. Difference in aesthetics and ergonomics of the FIs.

3. Method

To develop frugal products, designers need to acknowledge users' needs and wants during the product development phase. The ultimate goal of this study is to determine the essential attributes of

FI that can be incorporated during the early phase of design process. The method of determining the attributes consist of three steps (Figure 2), as given below:

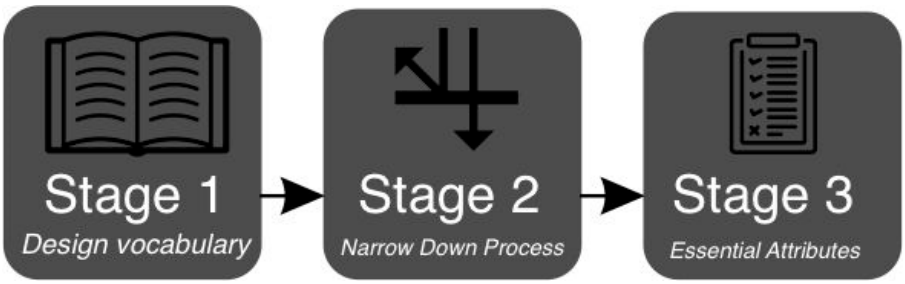

Figure 2. Methodology.

3.1. Design Vocabulary

A list of attributes that are associated with the design and users were collected from the journals, books, internet, design magazines, product catalogues and market survey. A list of more than a hundred words were identified and collected for the study, representing the design attributes based on the tangible/in tangle outcomes and user characteristics (e.g., functionality and usability extracted from tangible/in tangle outcomes i.e., product and product attachment/emotion is obtained from human experience). The objective of this step was to explore and create design vocabulary to identify the required attributes (Appendix A) [23–25].

3.2. Narrow Down Processes

The second step was to condense the database by eliminating the inappropriate words that were not directly associated with FI. All words that did not fall into the category of the product feature or attribute were excluded from the database (e.g., charity, health, heart, devotion, energy, etc.). Finally, the elimination of similar words was done. The number of attributes was condensed to more than twenty by neglecting words that appeared improper for expressing frugality. In this process, 30 design experts from academia and industry were involved to identify the relevant attributes by removing similar and inappropriate attributes from the design vocabulary.

The total number of attributes was narrowed down to 11 attributes, as shown in Table 1, after the focus group session with the design experts in which words are mapped with the definition of frugal design. Cumulative frequency distribution analysis was performed to identify the important attributes that are directly or indirectly related to frugality with the help of 30 design experts (Table 2). Cumulative frequency is an important tool in statistics, and also in data analytics; it helps to govern the number of observations that lie above (or below) a certain value in our dataset [26]. It is also used to extract the information from the dataset, i.e., decision making, trend analysis, forecasting, etc. Cumulative frequency distribution was tabulated with the help of distinct attributes and their corresponding occurrences. The analysis table based on cumulative frequencies was presented by the steps stated:

1. Absolute frequencies for each of the attributes were collected from the design experts.
2. Frequencies were arranged in descending order.
3. The cumulative frequency for each corresponding design attribute was further calculated.
4. Finally, the percentage corresponding to each attribute was calculated using the following formula:

$$Percentage\ (\%) = \frac{c\,f}{\sum_{i=1}^{n} f_i} * 100$$

where

cf = Cumulative frequency

$\sum f_i$ = Sum of absolute frequencies
n = Total number of attributes

Table 1. Attributes associated to frugality.

Filtered Attributes		
Functionality	Usability	Affordability
Accessibility	Performance	Aesthetics
Robustness	Human factors	Adaptability
Modularity	Attachment	

Table 2. Cumulative frequency distribution for predicting vital attributes.

S.No.	Attributes	Frequency	Cumulative Frequency	Percentage
1	Functionality	30	30	16.13
2	Usability	23	53	28.49
3	Affordability	23	76	40.86
4	Accessibility	22	98	52.69
5	Performance	21	119	63.98
6	Aesthetics	17	136	73.12
7	Robustness	13	149	80.11
8	Human factors	11	160	86.02
9	Adaptability	10	170	91.40
10	Modularity	10	180	96.77
11	Attachment	6	186	100.00

The cumulative frequency distribution analysis was applied to eliminate the uncertainties related to design attributes and to prioritize the root-cause and/or problem-solving. The cumulative frequency distribution chart, therefore, shows the relative frequency design attributes in a rank-order, and thus delivers a prioritization tool so that process improvement activities can be organized to get the most effective attributes towards the frugal innovation from others. The purpose of applying the cumulative frequency distribution analysis was to separate the "vital attributes" from the "trivial many", which was represented with the help of the cumulative frequency distribution chart.

Figure 3 and Table 2 shows the absolute frequency and cumulative frequency distribution of the 11 design attributes. After evaluating the cumulative frequencies and their corresponding percentage, we applied an evaluation rule on these attributes, which states that:

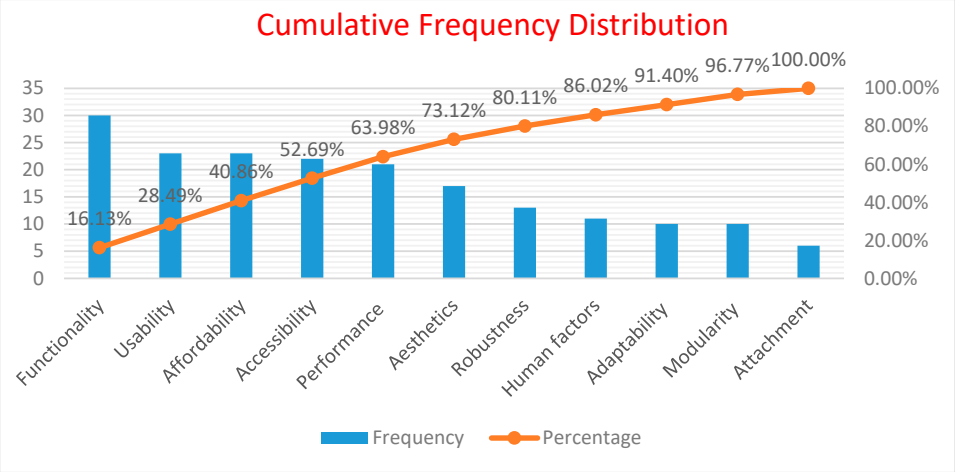

Figure 3. Cumulative frequency distribution analysis chart.

"All the attributes lying within 80% are recognized to be the vital attributes contributing towards frugal innovation".

This evaluation rule acts as a threshold in the cumulative frequency distribution analysis, predicting which among all the attributes lies above the stated threshold value, are recognized as the significant ones. Therefore, based on this evaluation rule, 7 attributes were recognized to significantly contributing towards frugal innovation, namely:

1. Functionality: The quality of being suited to serve a purpose well [27].
2. Affordability: Affordability is related to an economical bond that consumer experiences during the purchase of the product at an efficient price.
3. Usability: Ease of use and learnability of human made products.
4. Aesthetics: Concerned with emotions which evoke a sense of beauty and precision in relation to form, color, material and finish.
5. Robust: Product, service, and environment able to withstand or overcome adverse conditions and perform effectively.
6. Performance: The action or process of performing a task or function [27].
7. Accessibility: Products and environments should be designed to be usable by all sets of users without modifications.

Thus, the seven important attributes were pinned down for the development of frugal designs.

3.3. Essential Attributes

To determine the importance of each of these seven vital attributes towards a frugal innovation, a descriptive-analytical tool called the Relative Importance Index (RII) on the basis of a Likert scale was employed. The Relative Response Index is used for performing regressive analysis on the attributes that have been identified in the previous stage of cumulative frequency distribution. It acts as a predictor, which helps to gain insight to which of the given factors are the most important or are of lesser importance. In addition, with the help of RII, we can compare the responses from each of the group of respondents in order to draw a comparison among the factors, indicating which factor is more important to either of the sets of respondents in an ordered custom. In order to draw this conclusion, we again deployed a panel of design experts and design practitioners who are actively associated with the process of design innovation, that helped us determine the importance of these attributes, which was achieved by collecting individual responses on a 5-point Likert scale. There were three steps in carrying out this analysis, which are discussed in the subsequent sections.

3.3.1. Step I: Data Collection through Survey

In this step, a survey was conducted with 15 design experts and 25 design practitioners where they had to rate the seven attributes on the concept of importance for each of these attributes on a 5-point Likert scale of 1 to 5, 1 being the least important attribute and 5 being the most important attribute. Tables 3 and 4 represents the expert and end-user responses.

Table 3. Factors affecting designing of a frugal innovation (design expert responses).

	Response Per Frequency					
Attributes	**5—Most Important**	**4—Important**	**3—Moderately Important**	**2—Least Important**	**1—Not Important**	**Total Respondent**
Functionality	11	4	0	0	0	15 Design Experts
Usability	4	8	3	0	0	
Affordability	13	1	1	0	0	
Accessibility	0	2	7	5	1	
Performance	0	8	6	1	0	
Aesthetics	5	5	4	0	1	
Robustness	5	6	3	1	0	

Table 4. Factors affecting designing of a frugal innovation (design practitioner responses).

	Response Per Frequency					
Attributes	**5—Most Important**	**4—Important**	**3—Moderately Important**	**2—Least Important**	**1—Not Important**	**Total Respondent**
Functionality	14	10	1	0	0	25 Design practitioners
Usability	10	11	3	1	0	
Affordability	10	6	9	0	0	
Accessibility	2	6	9	6	2	
Performance	8	9	8	0	0	
Aesthetics	11	9	5	0	0	
Robustness	4	10	9	2	0	

3.3.2. Step II: Calculating Relative Importance Index (RII)

The data received by both set of respondents were then analyzed with the help of a descriptive statistical tool RII in order to determine the relative importance of each of these factors or attributes corresponding to a frugal innovation.

Mathematically, the Relative Importance Index is evaluated as follows:

$$\text{RII} = \frac{\sum_{i=1}^{5} W_i n_i}{A \times N}$$

where

RII = Relative Importance Index
W_i = Weights provided by ith respondent to each factor, ranging from i = 1 to 5
n_i = Total number of responses in each response category of the Likert scale
A = Highest weight in the Likert scale (i.e., "5")
N = Total number of respondents

Based on the responses from the design experts and the design practitioners, the RII evaluation for each of the factors from both sets of respondents is represented in Table 5.

Table 5. Evaluated Relative Importance Index (RII) values of the respondents.

Attributes	**Expert RII**	**Design Practitioner RII**
Functionality	0.947	0.904
Usability	0.960	0.808
Affordability	0.813	0.840
Accessibility	0.773	0.848
Performance	0.800	0.728
Aesthetics	0.693	0.800
Robust	0.533	0.600

3.3.3. Step III: Calculating Mean RII

To determine the contribution of each of these factors towards frugal innovation based on its importance, mean RII was calculated [28] from the RII values obtained from Table 5. Figure 4 illustrates the mean RII for each of these factors, and they are further categorized as most essential, essential, desirable, and neutral (refer Table 6 andTable 7).

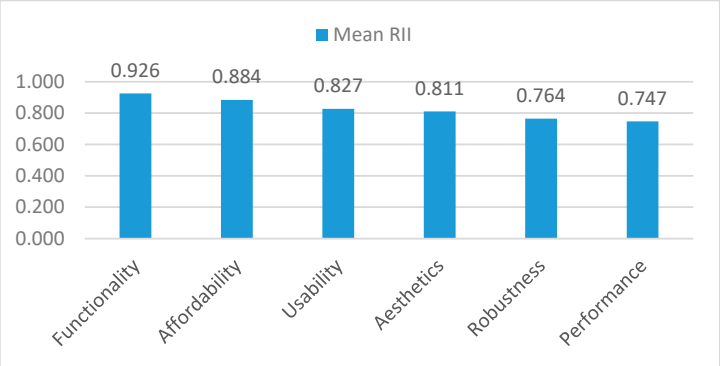

Figure 4. Mean Relative Importance Index (RII).

Table 6. Evaluation rule.

Attributes	Mean RII Range
Most essential	$(0.8 < RII \leq 1.0)$
Essential	$(0.6 < RII \leq 0.8)$
Desirable	$(0.4 < RII \leq 0.6)$
Neutral	$(RII \leq 0.4)$

Table 7. Mean RII values and corresponding categories.

Attributes	Mean RII	Category
Functionality	0.926	Most Essential
Affordability	0.884	Most Essential
Usability	0.827	Most Essential
Aesthetics	0.811	Most Essential
Robustness	0.764	Essential
Performance	0.747	Essential
Accessibility	0.567	Desirable

The importance of each of these factors was observed and recorded in Table 7, concluding that functionality, affordability, usability, and aesthetics are the most essential attributes. Robustness and performance represented essential attributes of frugal innovation. Attributes such as accessibility, falling under desirable attributes, will enhance the overall experience within the diverse population.

4. A Case Study of the Passenger Cars Based on Attributes

A case study of the passenger cars was then carried out to validate the method. Two economical passenger cars (Tata Nano and Renault Kwid—shown in Figure 5) were taken for this case study. These cars were chosen to investigate the product, based on the essential parameters of the FIs as the selected product served well for users belonging to the low and the middle income groups.

(**a**) (**b**)

Figure 5. Passenger car case study: (**a**) Tata Nano; (**b**) Renault Kwid.

The attributes associated to the frugal innovation such as explanation or details of the attributes were provided to the participants. The Likert-type questionnaire was handed over to the users and their response was recorded based on their experience and perception of using the selected product on a scale of 5, with the following labels: '++'excellent; '+' good; '0' average; '−' poor; and '−−'worse.

After investigating the responses in Table 8, it was observed that the TATA Nano performed well in terms of affordability, whereas the Renault Kwid performed extremely well in terms of aesthetics, usability, functionality, and affordability.

Table 8. Case study (i) TATA Nano, and (ii) Renault Kwid.

		Attributes	**Tata Nano**	**Renault Kwid**
7 Attributes of Frugal Innovation	**5 Expert Users**	Functionality	+	++
			++	++
			++	+
			0	+
			+	++
		Usability	+	++
			+	++
			+	++
			+	+
			0	++
		Affordability	++	++
			++	+
			++	++
			++	++
			++	+
		Accessibility	0	0
			0	0
			0	+
			0	−
			0	0
			−	
		Performance	0	0
			0	+
			+	+
			−	+
			+	0
		Aesthetics	+	++
			++	++
			++	+
			0	++
			−	++
		Robust	+	+
			+	+
			+	0
			0	+
			0	+
Total "+"			30	41
Total "−"			3	1
Total Score			27	40

The case study of the passenger car was useful to examine what attributes led to the failure of the design in terms of frugality. Affordability is not the only criteria which defines the frugality—other attributes such as functionality, usability, performance, aesthetics, robust, accessibility are also essential attributes of frugal innovation. The current frugal design approach is more focused on cost reduction, functionality, and performance sustainability [29]. Although these are very important attributes to develop effective products in terms of economy, productivity, and ecology aspect of the design spectrum [30,31], social inclusion is completely neglected in current practice, and the inclusion of all sets of users into consideration will help to map the product on the social, ecological and economic scale, and enhance the acceptability among the diverse user sets. The product would be productive if users found its appearance to be elegant and comfy to use. Designers need to consider aesthetics during the initial design process as aesthetics plays a vital role to enhance the reachability and scalability of the product.

5. Conclusions

Frugal innovation is a professional design process that helps to reduce the complexity and cost of the product while at the same time increasing the efficiency of the product. The identification of essential attributes is the initial step towards true frugal innovation. This study identifies the seven essential attributes of frugal innovation with the help of 80/20 analysis and the Relative Importance Index (RII). A case study was performed to investigate the attributes of FI that helped us to analyze whether the identified attributes from our experiment are true to their cause for designing a frugal innovation. TATA Nano was the case study that was undertaken which turned out to be an affordable product but not effective in terms of aesthetics, usability, functionality, and affordability. Negligence of these attributes during the initial design phase creates the prejudicial effect of being labeled as a low-cost product "Jugaad", which conflicts with the objective of frugality. The product would be productive if users found its appearance to be elegant and comfy to use. There are numerous products under the label of "Jugaad" but are not considered mainstream products among the users; because of a perception of disgrace/awkwardness attached to them. Therefore, in many instances, even marginalized communities avoid using the product that is specially designed for them. Designers need to consider aesthetics during the initial design process, as aesthetics plays a vital role to enhance the reachability and scalability of the product. Thus, based on the observation and the case study carried out, it can be concluded that if the designer considers these seven attributes in the initial design phase of the product design process, the product would be frugal in every sense—that is, in terms of cost, function and aesthetics. The proposed framework is effective to eradicate the discriminatory effect of being labeled as "Jugaad" users.

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Appendix A

Table A1. List of attributes.

Human factors, Innovation	Refinement	Economy
Usefulness	Recreation	Consistency
Usability	Relaxation	Capability
Aesthetics	Desire	Bliss
Self-explanatory	Energy	Justice
Affordance	Respect	Maturity
Honest	Sympathy	Control
Simple	Relief	Contribution
Comfort,	Hope	Capability
Acceptance,	Want	Energy
Redundancy	Adaptability	Security
Balance	Challenge	Self-reliance
Accessibility	Fitness	Stability
Capacity	Flexibility	Support
Accuracy	Cheerfulness	Surprise
Intuitive	Friendliness	Amused
Flexibility	Frugality	Peaceful
Feedback	Fun	Alert
Adaptability	Direction	Attachment
Modularity	Commitment	Perfect
Interactive	Confidence	Helpfulness
Performance	Appreciation	Honor
Functionality	Availability	Hopefulness
Product attachment	Awareness	Courage
Intuition	Beauty	Courtesy
Elegance	Connection	Order
Empathy	Gratitude	Originality
Enjoyment	Growth	Motivation
Entertainment	Guidance	Courage
Hospitality	Vision	Uniqueness
Creativity	Unity	Proactive
Hygiene	Prosperity	Richness
Imagination	Professionalism	Utility
Impact	Resolve	
Excitement	Reliability	
Pleasure	Simplicity	
Insightfulness	Satisfaction	
Inspiration	Togetherness	
Understanding	Independent	
	Aspiration	

References

1. Leliveld, A.; Knorringa, P. Frugal Innovation and Development Research. *Eur. J. Dev. Res.* **2017**, *30*, 1–16. [CrossRef]
2. Brem, A. Linking innovation and entrepreneurship—Literature overview and introduction of a process-oriented framework. *Int. J. Entrep. Innov. Manag.* **2011**, *14*, 6–35. [CrossRef]
3. Drazin, R.; Schoonhoven, C.B. Community, Population, and Organization Effects on Innovation: A Multilevel Perspective. *Acad. Manag. J.* **1996**, *39*, 1065–1083.
4. Christensen, C.M. *The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail*; Harvard Business Review Press: Boston, MA, USA, 2013.
5. Chandy, R.K.; Hopstaken, B.; Narasimhan, O.; Prabhu, J.C. From Invention to Innovation: Conversion Ability in Product Development. *J. Mark. Res.* **2006**, *43*, 494–508. [CrossRef]

6. Jon-Arild, J.; Bjørn, O.; Lumpkin, G.T. Innovation as newness: What is new, how new, and new to whom? *Eur. J. Innov. Manag.* **2001**, *4*, 20–31.
7. Govindarajan, V.; Trimble, C. Organizational DNA for strategic innovation. *Calif. Manag. Rev.* **2005**, *47*, 47–76. [CrossRef]
8. Gardner, P.L. The Globalization of R&D and International Technology transfer in the 21st century. In Proceedings of the International Conference of Management of Innovation and Technology (ICMIT'02 & ISMOT'02), Hangzhou, China, 18–20 October 2002; Volume 3, p. 5.
9. Zeschky, M.; Widenmayer, B.; Gassmann, O. Frugal Innovation in Emerging Markets. *Res. Manag.* **2011**, *54*, 38–45. [CrossRef]
10. Agarwal, N.; Brem, A. Frugal and reverse innovation-Literature overview and case study insights from a German MNC in India and China. In Proceedings of the 2012 18th International ICE Conference on Engineering, Technology and Innovation, Munich, Germany, 18–20 June 2012; pp. 1–11.
11. Saraf, D. India's Indigenous Genius: Jugaad—WSJ. 2009. Available online: https://www.wsj.com/articles/SB124745880685131765 (accessed on 29 July 2020).
12. Singh, R.; Das, P.P. An Approach to Develop Accessible and Affordable Products. *Procedia CIRP* **2020**, *91*, 489–493. [CrossRef]
13. Immelt, J.R.; Govindarajan, V.; Trimble, C. How GE is disrupting itself. *Harv. Bus. Rev.* **2009**, *87*, 56–65.
14. Singhal, V. The impact of emerging economies innovative new models of global growth and vitality are emerging. *Visions* **2011**, *35*, 12–14.
15. Brem, A.; Ivens, B.S. Do Frugal and Reverse Innovation Foster Sustainability? Introduction of a Conceptual Framework. *J. Technol. Manag. Grow. Econ.* **2013**, *4*, 31–50. [CrossRef]
16. Weyrauch, T.; Herstatt, C. What is frugal innovation? Three defining criteria. *J. Frugal Innov.* **2016**, *2*, 1. [CrossRef]
17. Von Zedtwitz, M.; Corsi, S.; Søberg, P.V.; Frega, R. A typology of reverse innovation. *J. Prod. Innov. Manag.* **2015**, *32*, 12–28. [CrossRef]
18. Knorringa, P.; Peša, I.; Leliveld, A.; Van Beers, C.; Knorringa, I.P.P. Frugal innovation and development: Aides or adversaries? *Eur. J. Dev. Res.* **2016**, *28*, 143–153. [CrossRef]
19. Hossain, M. Frugal innovation: A review and research agenda. *J. Clean. Prod.* **2018**, *182*, 926–936. [CrossRef]
20. Rao, B.C. How disruptive is frugal? *Technol. Soc.* **2013**, *35*, 65–73. [CrossRef]
21. Hossain, M.; Simula, H.; Halme, M. Can frugal go global? Diffusion patterns of frugal innovations. *Technol. Soc.* **2016**, *46*, 132–139. [CrossRef]
22. Simula, H.; Hossain, M.; Halme, M. Frugal and reverse innovations quo vadis? *Curr. Sci.* **2015**, 1567–1572. [CrossRef]
23. Falvo, D.A.; Urban, M.; Lidwell, W.; Holden, K.; Butler, J. Universal Principles of Design. *Educ. Technol. Res. Dev.* **2007**, *55*, 297–300. [CrossRef]
24. Desmet, P.M.A. Faces of product pleasure: 25 positive emotions in human-product interactions. *Int. J. Des.* **2012**, *6*, 2.
25. Desmet, P.; Hekkert, P. Framework of product experience. *Int. J. Des.* **2007**, *1*, 57–66.
26. Chakraborty, P. Histogram equalization by cumulative frequency distribution. *Int. J. Sci. Res. Publ.* **2012**, *2*, 7.
27. Singh, R.; Tandon, P. Framework for improving universal design practice. *Int. J. Prod. Dev.* **2018**, *22*, 377–407. [CrossRef]
28. Aswathi, P.; Wilson, A. Study on Critical Performance Factors Affecting Kochi Metro Rail Project. *Int. J. Adv. Sci. Res. Eng.* **2020**, *6*, 107–112.
29. Winkler, T.; Ulz, A.; Knöbl, W.; Lercher, H. Frugal innovation in developed markets—Adaption of a criteria-based evaluation model. *J. Innov. Knowl.* **2019**. [CrossRef]
30. Singh, R.; Tandon, P. A Sustainable Approach to Develop Universal Products. In Proceedings of the 6th International Kansei Engineering and Emotion Research Conference, Leeds, UK, 31 August–2 September 2016.
31. Saxena, P.; Stavropoulos, P.; Kechagias, J.; Salonitis, K. Sustainability Assessment for Manufacturing Operations. *Energies* **2020**, *13*, 2730. [CrossRef]

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